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For the President of the European Patent Office

Le Président de l'Office européen des brevets  
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Cross interleave reed-solomon code correction

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**Cross interleave Reed-Solomon code correction**

This invention relates generally to a method and apparatus for performing error correction on digital data using a Reed-Solomon code, and more particularly, to a method and apparatus for cross interleave Reed-Solomon code correction.

Background

10

One error correction code that is typically used in compact audio discs is the so-called CIRC correction code. CIRC is an acronym for Cross Interleave Reed-Solomon Code. In the case of the CIRC correction code, the encoding process of the (28, 24) Reed-Solomon code (C2 code) is performed for twenty-four data symbols, with each symbol consisting of 8 bits. In such typical audio applications each audio sample is 16 bits, which is formed of two symbols of 8 bits each. Thus, each 8-bit symbol is either the upper or lower side of an audio sample of one of the two channels of stereophonic audio data.

20

These data symbols are in a first state of arrangement and, next, the data is rearranged from the first arrangement state to a second state of arrangement by an interleaving operation. The encoding process of the (32, 28) Reed-Solomon code (C1 code) is then executed for the twenty-eight symbols that are now in the second arrangement state. When decoding the CIRC correction code, the C1 decoding is performed first, then the de-interleave is performed and, thereafter, the C2 decoding is performed.

30

Various methods of decoding the CIRC correction code are already known, and examples of such methods are disclosed in US-A-4 546 474, US-A-4 476 562 and US-A-4 497 058, for example. On the other hand, various methods of decoding the Reed-Solomon code are also known, and examples of such meth-

35

ods are disclosed in US-A-4 476 562.

According to the conventional decoding methods of the CIRC  
correction code, error processing up to and including dou-  
5 ble-error correction is executed in the C1 decoding in the  
first stage, and double-error correction is executed in the  
C2 decoding at the next stage by referring to pointer infor-  
mation that is derived from the C1 decoding.

10 One method of decoding the error correction code that has  
been proposed is the so-called erasure correction method, in  
which the location of the error symbol is indicated by  
pointer information and the necessary correction is per-  
formed on this error symbol. In the case of the above-  
15 mentioned C1 and C2 codes, detection and correction up to  
and including double errors (two symbols) can be respec-  
tively performed. However, if the error location is already  
known, then error correction up to and including quadruple  
errors (four symbols) can be performed.

20 Therefore, in order to raise the error correction capabil-  
ity, it has been preferred to perform the erasure correction  
method of decoding the error. Furthermore, the erasure cor-  
rection method has been found to be particularly effective  
25 in correcting burst errors. On the other hand, in order to  
perform the erasure correction operation properly, the error  
locations must be preliminarily known from the pointer in-  
formation and, moreover, the reliability of that pointer in-  
formation must be relatively high.

30 According to the conventional coding method of the CIRC cor-  
rection code, error correction up to and including double  
errors is executed in the C1 decoder. In such case, because  
there is a fear of the occurrence of triple errors, which of  
35 course could not be corrected, the C1 pointer is sent to the  
C2 decoder in the next stage, so that error correction is

executed in the C2 decoder using the C1 pointer.

More specifically, in the case of the conventional CIRC correction code, the series of the C1 code (C1 series) is  
5 formed by 32 symbols that are alternately included in two adjacent frames (one frame: 32 symbols). The series of the C2 code (C2 series) is formed by 28 symbols that are included in predetermined ones of 108 consecutive frames. Because the interleave length of the C1 series is shorter than  
10 that of the C2 series, when a fast-forward reproduction operation, such as queuing or review, is performed, a problem occurs in that some frames are dropped and the continuity of the frames is lost.

That is, the C1 pointer is used to indicate the presence of  
15 errors in the one frame before and after the point of the discontinuity, however, the C1 pointer only indicates the absence of the errors in the other frame. On the other hand, the interleave length of the C2 series has 108 frames, and these 108 frames will include the point of discontinuity.  
20 Thus, this is also not the correct C2 series. Upon performing the erasure correction for the incorrect C2 series by use of the foregoing C1 pointer, the error correction will be incorrect.

25 To solve this problem of incomplete or incorrect error correction when performing error correction of the CIRC correction code, wherein the maximum error correcting capability is obtained by the erasure correction method, there has been proposed an error correction method wherein the C1 decoding  
30 and C2 decoding are executed twice in a specific order (such double-execution of C1 decoding and C2 decoding is disclosed in US-A-4 637 021). That order might be, for example, C1 decoding, followed by C2 decoding, followed by C1 decoding, and followed by C2 decoding. In the first C2 decoding, erasure  
35 correction is performed using the C1 pointer obtained by the C1 decoding at the front stage and the erroneous cor-

rection that may occur at this erasure correction is prevented by the second C1 decoding and the C2 decoding, which are similar to the conventional method of decoding the CIRC correction code.

5

EP-A-0 278 383 shows an error correction method using Reed-Solomon code. When the error correction is performed by using the result of the multiplication of a syndrome and an error location, another syndrome is added to thereby form a  
10 new syndrome. By repetitively executing this procedure, the error vector is obtained by a number of arithmetic operations, thereby performing error correction by the so-called erasure correction technique. Then, by calculating another error vector using the first calculated error vector, the  
15 number of arithmetic operation times can be reduced.

Figure 1 is a block diagram to illustrate conventional cross interleave Reed-Solomon code (CIRC) decoding of the Reed-Solomon (RS) codes. The main tasks of the CIRC decoder are  
20 to perform:

1. Delaying incoming data by one-symbol;
2. Decoding the C1 code (32, 28) and correcting erroneous symbols;
3. De-interleaving;
- 25 4. Decoding the C2 code (28, 24) and correction of erroneous symbols;
5. Delay of two symbols.

32 symbols of incoming data form one frame and are supplied  
30 to the time delay circuit (delay of one-symbol), in which only the even numbered symbols are delayed by an amount to one frame. 32 symbols output from the time delay circuit are supplied to a C1 decoder, in which the actual decoding of the (32, 28) Reed-Solomon code (C1 code word) is executed.  
35 The error correction of up to two errors symbol in a C1 code word is performed in the C1 decoder. When three or more er-



rors are detected in a C1 decoder, the C1 pointer (erasure flag) is set for all symbols in a C1 code word. The data and erasure flags are further processed in the de-interleave circuit (delay lines of unequal length).

5 The output of the de-interleave circuit is supplied to a C2 decoder. In the de-interleave circuit the erasure flag of each symbol generated from a C1 decoder is de-interleaved in a manner similar to the de-interleave of the data. The erasure correction of up to four errors is executed in a C2 decoder by use of the C1 erasure flags.

10 If correction of up to four error symbols is possible by a C2 decoder then a C1 erasure flags are cleared. If it is not possible then either the C1 erasure flags in a C2 code word are copied or erasure flags to all symbol of a C2 code word are set. The last stage in the CIRC decoding is a two-symbol delay. It is executed by a two-symbol delay circuit. Double usage of the CIRC correction codes leads to an increase of the correcting capability of the error correction system.

20

### Invention

However, it is a common disadvantage of such conventional CIRC decoders of the type as shown in Fig. 1 that they are incapable of double processing of blocks of the CIRC codes.

It is therefore an object of the present invention to provide for an improved method for CIRC correction and an improved computer program and Reed-Solomon decoder for CIRC correction.

30 The present invention provides for an improved method for CIRC correction in accordance with claim 1. Further the present invention provides for an improved computer program and Reed-Solomon decoder in accordance with the further independent claims.

Preferred embodiments of the invention are given in the dependent claims.

The present invention enables single pass and double pass  
5 operation of the CIRC decoder.

One-symbol delay operation, two-symbol delay operation and the double or single decoding of the CIRC correction code are achieved by using four separate memories, and by the special controlling and addressing of each memory.

10

The present invention is particularly advantageous in that it enables double processing of blocks of the CIRC codes.

15 Drawings

Exemplary embodiments of the invention are described with reference to the accompanying drawings, which show in:

Fig. 1 block diagram of a prior art CIRC decoder;

20 Fig. 2 block diagram illustrating the first pass of a CIRC decoder in accordance with an embodiment of the invention;

Fig. 3 block diagram illustrating the second pass of the decoder of Fig. 2;

25 Fig. 4 block diagram illustrating an alternative embodiment of a CIRC decoder;

Fig. 5 flow chart for the operation of the CIRC decoder for double and single processing of the CIRC correction code;

30 Fig. 6 scheme illustrating the data flow in the M1 memory;

Fig. 7 block diagram illustrating the calculation of addresses in the M1 memory;

Fig. 8 illustration of the operation of the memory M2,a;

35 Fig. 9 further illustration of the operation of the memory M2,a;

Fig. 10 block diagram illustrating the calculation of ad-

addresses in the M2 memory;

Fig. 11 characteristic lines illustrating the results of correction of different burst errors.

5

#### Exemplary embodiments

Fig. 2 shows a block diagram of a CIRC decoder. The decoder has a memory M1 for storage of C1 code words (CW). Further  
10 there is a C1 decoder, a memory M2,a with associated de-interleaver D1, a memory M2,b within an associated de-interleaver D2, a C2 decoder and a memory M3.

At the beginning of the first pass the C1 CW is stored in the memory M1. From there the C1 CW is inputted into the C1  
15 decoder. The C1 decoder outputs another C1 CW into M2,a. The C1 CW which is outputted from the C1 decoder is a copy of the C1 CW of memory M1, if the C1 CW of memory M1 is not correctable.

In this instance the erasure flags are set for all the symbols within the C1 CW. If the C1 CW of memory M1 is correct-  
20 able the C1 CW which is outputted from the C1 decoder is the corrected C1 CW of memory M1.

A de-interleaving operation is performed by means of de-interleaver D1. As a result a C2 CW is stored in memory  
25 M2,a. The C2 CW of memory M2,a is inputted into the C2 decoder. The C2 decoder writes a C2 CW back to memory M2,a. This C2 CW is either a copy of the original C2 CW in case the original C2 CW is not correctable, or it is the corrected C2 CW. When the C2 CW is not correctable again the  
30 erasure flags are set.

Figure 3 is illustrative of the second pass. The C1 CW of M2,a is inputted into the C1 decoder. The C1 decoder outputs a C1 CW into memory M2,b. The C1 CW of memory M2,b is either  
35 a copy of the C1 CW of memory M2,a in case the C1 CW of memory M2,a is not correctable, or it is the corrected C1 CW of

the memory M2,a. In case the C1 CW of memory M2,a is not correctable the erasure flags are set in the codeword C1 CW which is outputted from C1 decoder and stored in memory M2,b.

- 5 The de-interleaver D2 is started. As a result a codeword C2 CW is provided in memory M2,b. This is inputted into the C2 decoder. The C2 decoder outputs a codeword C2 CW into memory M3. The C2 CW which is outputted by the C2 decoder is either a copy of the C2 CW of memory M2,b in case the C2 CW of mem-  
10 ory M2,b is not correctable, or it is the corrected C2 CW of memory M2,b. In case the C2 CW of memory M2,b is not correctable the erasure flags are set.

In the following a more detailed embodiment will be de-  
15 scribed:

#### *System Components*

Figure 4 illustrates the block diagram of the CIRC decoder  
20 showing the major components of the CIRC decoder (double and single pass of the CIRC decoder is implemented in this architecture).

The data stream from the acquisition part is stored into an input logic 1. The input logic is able to store 32 symbols.  
25 If sufficient data is available in the buffer of the input logic then a frame is stored into the M1 memory. M1 memory is used for one-symbol delay task of the CIRC decoder. The MUX1 multiplexer 3 is used to multiplex the data either from the M1 memory to the C1 decoder or from the M2,a memory to  
30 the C1 decoder depends on the pass of the CIRC decoder.

The block 4 is the conventional RS decoder. In this block a so-called erasure correction method of RS code is implemented. RS decoder 4 is able to correct four erasures or two  
35 errors or any combinations of errors and erasures under the condition:  $2*t+E < d$ , where t-number of errors in a code word,

E-number of erasures, d-Hamming distance of the RS code (d = 5 for compact audio disc application).

A flag processor block No.1 (block 5) generates the error status of the C1 decoder and defines an output erasure flag.

5 A demultiplexer (DEMUX1) 6 is used for de-multiplexing the C1 decoder output either to the M2,a memory or to a register (buf\_reg) 8. The output of demultiplexer 6 depends on the pass of the CIRC decoder.

An M2,a memory 7 is used for the de-interleaving and for assembling C1 code words in C2 code words during the first  
10 pass of the CIRC decoder. Register 8 is used to memorise the corrected C1 code word. An M2,b memory 9 is used for the de-interleaving and for assembling C1 code words in C2 code words during the second pass of the CIRC decoder. A control-  
15 ler 10 of the CIRC decoder performs the memories management during the following tasks:

- a) One-symbol delay task;
- b) C1 decoder task;
- c) De-interleave and C2 decoder task;
- 20 d) Two-symbol delay task.

A multiplexer 11 (MUX2) is used to multiplex the data either from the M2,a memory to the C2 decoder or from the M2,b memory to the C2 decoder, depending on the pass of the CIRC de-  
25 coder. Block 12 is a conventional RS decoder. This decoder has the same performance like the RS decoder 4.

The flag processor block No.2 (block 13) generates the error status of the C2 decoder and defines an output erasure flag. An M3 memory 14 is used for the two-symbol delay task of the  
30 CIRC decoder. An output logic 15 is used to store 24 symbols from the M3 memory.

#### *Controlling the data in the CIRC decoder*

35 The operation of the CIRC decoder for double and single processing of the CIRC correction code is depicted by the

flow diagram of Fig. 5.

If the `nxt_frame` signal is active (step 2) then a frame is loaded from input logic into the corresponding bank of the M1 memory and the one-symbol delay task is executed (step

5 3).

During step 4 the data are transferred from the M1 memory (see Fig. 4) through the MUX1 multiplexer to the C1 decoder. At the same time the syndrome is calculated. The decoding process C1 is started after transferring 32 symbols.

10 The de-interleaver task (step 5) is performed in the M2,a memory. 28 symbols of the C2 code word are transferred from the M2,a memory through MUX2 multiplexer to the C2 decoder. At the same time the syndrome is calculated. The decoding process C2 is started after transferring 28 symbols.

15 After start of the C1, C2 processes, the controller waits for an even - C1 process ready (step 6). If the C1 process is ready a C1 code word from a C1 decoder is written into the M2,a memory (step 7). Then the controller is waiting for an even - C2 process ready (step 7).

20 The next step in the data flow depends on single or double pass operation of the CIRC decoder (step 9). If the CIRC decoder performs single pass and the C2 process is ready then a corrected C2 code word from the C2 decoder is written into the M3 memory. Then the two-symbol delay task is performed  
25 into the M3 memory. Afterwards a corresponding data item is loaded into output logic (step 16).

If the CIRC decoder performs double pass and the C2 process is ready then a corrected C2 code word from the C2 decoder is written into the M2,a memory (step 10) and the second  
30 pass of the CIRC decoder is to be started.

The C1 code word is transferred from the M2,a memory through MUX1 multiplexer to the C1 decoder. At the same time the syndrome is calculated. The decoding process C1 is started after transferring 32 symbols (step 11).

35 The de-interleaver task (step 12) is performed in the M2,b memory. 28 symbols of the C2 code word are transferred from

the M2,b memory through the MUX2 multiplexer to the C2 decoder. At the same time the syndrome is calculated. The decoding process C2 is started after transferring 28 symbols.

- 5 After start of the C1, C2 processes, the controller waits for an even - C1 process ready (step 13).  
If the C1 process is ready then the corrected C1 code word from a C1 decoder is written into buf\_reg (step 14).  
If the C2 process ready then the corrected C2 code word from  
10 a C2 decoder is written into the M3 memory (step 16).  
Then the two-symbol delay task is performed into the M3 memory. Thereafter a corresponding data item is loaded into output logic (step 16).  
The counters are updated during the step 18. Following step  
15 18, the ECC block is ready to process a new frame from the input logic.

#### *Addressing the data in the CIRC decoder*

- 20 Addressing and determining locations in different memories and controlling the transferred data bytes at read and write operations, during the one-symbol delay, de-interleaving and two-symbol delay operations, are performed using controller  
11.

25

#### *One-symbol delay task*

- The M1 memory is used for the one-symbol delay task of the CIRC decoder and comprises three banks with the addresses 0,  
30 1, and 2. Each bank consists of 32 symbols. Each symbol contains 9 bytes. The MS bit is "erasure flag", (7:0) bits are the data. An erasure bit indicates that a symbol is corrupted. If sufficient data is available in the buffer of the input logic then a frame is stored into the corresponding  
35 bank of the M1 memory and the one-symbol delay operation is executed.

Fig. 6 illustrates the data flow in the M1 memory. The M1 memory has a circular nature. The data flow in the M1 memory is repeated after 3 next\_frame signals, i.e. Fig. 6a and Fig. 6d are identical.

5

Fig. 7 illustrates the calculation of addresses in the M1 memory. A frame from the input logic is loaded into the corresponding bank of the M1 memory. The bank address is calculated according to the formula:

10

$$\text{bank\_add\_m1\_w} = \text{count\_m1\_w},$$

where count\_m1\_w counter defines the bank address in the M1 memory during the writing operation.

32 symbols are loaded into the corresponding symbol addresses of a bank. The count\_b\_m1 counter defines the symbol addresses into a bank. The bank address for the reading the M1 memory depends on the even or odd symbol.

15

The bank addresses are calculated according to the formulas:

$$\text{bank\_add\_0\_m1\_r} = \text{count\_m1\_r}, \quad // \text{even}$$

20

$$\text{bank\_add\_1\_m1\_r} = (\text{count\_m1\_r} + 2) \% 3 // \text{odd}$$

The bank address defines the count\_m1\_r counter and mod3 circuit. A symbol from the M1 memory is loaded in the TR temporal register (see Fig. 7). Whether a byte is inverted depends on the counter state of the count\_b\_m1 counter (if count\_b\_m1 = 12, 13, 14, 15, 28, 29, 30, 31 then to be inverted). An erasure bit is not inverted.

25

Delayed symbols are transferred to the syndrome generator of the C1 decoder during the first pass.

30

*De-interleaver task during first pass of the CIRC decoder*

The M2,a memory is used for the de-interleaving and the assembling of C1 code words in C2 code words and comprises 110 banks. Each bank consists of 32 symbols. Each symbol contains 9 bits. The task of the de-interleaver is de-interleaving C1 code words and the assembling of de-interleaved

35



C1 code words into C2 code words.

The de-interleaver task is performed in the M2,a memory during the first pass of the CIRC decoder by corresponding addressing of the M2,a memory. The de-interleaver task is performed after C1 decoding, correction and storage of a C1 corrected code word into the M2,a memory. The M2,a memory has the circular nature.

Fig. 8 and 9 illustrate the M2,a memory. For good understanding one can describe the M2,a memory as elements of a two-dimensional Cartesian coordinate system (Fig. 9). The vertical Y axis positions each contain 32 symbols of data (C1 code word). Each horizontal X axis represents a symbol (9 bits) at each Y axis position. Symbols are numbered sequentially within each Y axis position moving from left to right.

The symbols comprising C2 code words are lying along a diagonal line in the M2,a memory space. The symbols of a C2 code word in the 1, 2, 3, 4, 54 and 108 decoder cycles are shown in Fig. 9. In successive decoding cycles, the symbols comprising a C2 code word are changed. The initially positioned symbol for writing a C2 code word is located at Y position 0 and at X position 0 (Fig. 8).

The general formula for calculating the addresses of symbols in the C2 code word is

$$\text{add\_c2} = (\text{count\_rsd} + 4 \cdot I) \% \text{mod } 110,$$

where count\_rsd is the counter of decoder cycles (0, ..., 109), which defines the Y position (bank of memory), and where I has values of from 0 to 27.

#### *De-interleaver task during second pass of the CIRC decoder*

De-interleaver task during the second pass of the CIRC decoder is performed in the M2,b memory. It is a typical de-interleaver having delay lines of unequal length (see Fig.

1). The de-interleaver task is performed after C1 decoding, correction and storage a C1 corrected code word into the buf\_reg register.

5    *Addressing data in M2,a memory during read+write operation*

The C1 and the C2 decoder are operating concurrently on the data in the CIRC decoder. The C1 decoder is operating on the data ahead of the C2 decoder. Output of the C1 decoder  
 10    (first pass) is initially positioned for writing the C1 code word at Y position 109 (Fig. 8). In each succeeding decoder cycle the output of the C1 decoder is positioned for and writes the corrected C1 code word at the next successively higher valued Y positions (109, 0, 1, ... 0).

15    Input of the C1 decoder (second pass) is initially positioned for writing the C1 code word at Y position 0 (Fig. 8). In each succeeding decoder cycle the input of the C1 decoder is positioned for and reads the C1 code word at the next successively higher valued Y position (0, 1, 2, ...).

20    The initially positioned symbol for writing a C2 code word is at Y position 0 and at X position 0 (Fig. 8).

Data processing of the M2,a memory for the double pass of the CIRC decoder (see Fig. 5 and 8) includes the following  
 25    steps:

- 1) De-interleaving, read a C2 code word from M2,a to the C2 decoder;
- 2) Writing the corrected a C1 code word from the C1 decoder into the M2,a memory;
- 30    3) Writing the corrected C2 code word from the C2 decoder into the M2,a memory;
- 4) Read a C1 code from the M2,a memory to the C1 decoder.

Data processing of the M2,a memory for the single pass of  
 35    the CIRC decoder (see Fig. 5 and 8) includes the following steps:

- 1) De-interleaving, read a C2 code word from M2,a to the C2 decoder;
- 2) Writing the corrected C1 code word from the C1 decoder into the M2,a memory.

5

Fig. 10 (address generator) illustrates the calculation of addresses in the M2,a memory (add\_m2) during the corresponding steps. The count\_rsd counter defines a decoder cycle and is the basic counter to calculate a different bank address of M2,a memory during the write and read operations. The count\_b\_m2\_c1 counter defines a symbol address in a bank (counter counts up to 31). The count\_b\_m2\_c2 counter defines a symbol address in a bank (counter counts up to 27). With each +1 sym\_add the count\_b\_m2\_c1 counter and the count\_b\_m2\_c2 counter are counting up.

The subblock 1 calculates the addresses during the 1st step of double pass of the CIRC decoder.

The formula for calculation of the bank addresses of the M2,a memory is

20         $\text{bank\_add} = (\text{count\_rsd} + 4 * \text{count\_b\_m2\_c2}) \% \text{mod } 110,$   
 where the count\_b\_m2\_c2 counter defines the address of symbol in a bank.

The symbols are read from the M2,a memory to the C2 decoder according to these addresses. The subblock 2 calculates the addresses during the 2nd step of double pass.

The formula for calculation of the bank addresses of the M2,a memory is

30         $\text{bank\_add} = (\text{count\_rsd} + 109) \% \text{mod } 110,$   
 where the count\_b\_m2\_c1 counter defines the address of symbol in a bank.

Symbols of corrected C1 code word are written from the C1 decoder to the M2,a memory according to these addresses.

The subblock 3 calculates the addresses during the 3rd step of double pass.

35        The formula for calculation of the bank addresses of the M2,a memory is

bank\_add = (count\_rsd + 4\* count\_b\_m2\_c2)%mod 110,  
 where the count\_b\_m2\_c2 counter defines the address of symbol in a bank. Symbols of corrected C2 code word are written from the C2 decoder to the M2,a memory according to these  
 5 addresses.

The subblock 4 calculates the addresses during the 4th step of double pass.

The formula for calculation of the bank addresses of the M2,a memory is

10 bank\_add = (count\_rsd + 109)%mod 110,  
 where the count\_b\_m2\_c1 counter defines the address of symbols in a bank.

The symbols are read from the M2,a memory to the C1 decoder according to these addresses.

15

*De-interleaver task during second pass of the CIRC decoder*

For this task to be used the conventional de-interleaver has delay lines of unequal length, see Fig. 1. This de-  
 20 interleaver has been implemented in the M2,b memory.

*Two symbol delay task*

The M3 memory is used for the two-symbol delay task in the  
 25 CIRC decoder and comprises three banks with the addresses 0, 1, 2. The bank0 consist of 28 symbols, the bank1 and the bank2 each consist of 24 symbols. Data after C2 decoding and correction are loaded into bank0.

Two-symbol delay task comprises two steps:

- 30 1) Read the delayed data to the output logic;  
 2) Overwriting the M3 memory.

The following table 1 is used to generate the addresses during the first step:

count_b	0	1	2	3	4	5	6	7	8	9	10	11
bank	0	0	0	0	2	2	2	2	0	0	0	0
sym_add	0	1	6	7	4	5	6	7	2	3	8	9

count_b	12	13	14	15	16	17	18	19	20	21	22	23
bank	2	2	2	2	0	0	0	0	2	2	2	2
sym_add	12	13	14	15	4	5	10	11	20	21	22	23

wherein count\_b is a byte counter, bank is the bank address in the M3, and sym\_add is the symbol address in a bank.

- 5 The following table 2 is used to generate the addresses during the second step (read/write).

count_b	0	1	2	3	4	5	6	7	8	9	10	11
bank_r	1	1	1	1	0	0	0	0	1	1	1	1
sym_add	4	5	6	7	16	17	22	23	12	13	14	15
bank_w	2	2	2	2	1	1	1	1	2	2	2	2
sym_add	4	5	6	7	4	5	6	7	12	13	14	15

count_b	12	13	14	15	16	17	18	19	20	21	22	23
bank_r	0	0	0	0	1	1	1	1	0	0	0	0
sym_add	18	19	24	25	20	21	22	23	20	21	26	27
bank_w	1	1	1	1	2	2	2	2	1	1	1	1
sym_add	12	13	14	15	20	21	22	23	20	21	22	23

- 10 Results of the simulation of the CIRC decoder (double pass)

Fig. 11 shows the results of correction of different burst errors. Correction results of a conventional CIRC decoder are depicted by solid lines, the results for the inventive CIRC decoder are depicted in dashed lines.

The following error combinations were input for the correction:

- 1) Burst error of 20 C1 code words with 3 errors in each code word(random errors);
- 20 2) Burst error of 20 C1 code words with 4 errors in each code word;
- 3) Burst error of 20 C1 code words with 5 errors in each code word;

- 4) Burst error of 20 C1 code words with 6 errors in each code word;
  - 5) Burst error of 30 C1 code words with 3 errors in each code word;
  - 5 6) Burst error of 30 C1 code words with 4 errors in each code word;
  - 7) Burst error of 30 C1 code words with 5 errors in each code word;
  - 8) Burst error of 30 C1 code words with 6 errors in each code word;
  - 10 9) Burst error of 40 C1 code words with 3 errors in each code word;
  - 10) Burst error of 40 C1 code words with 4 errors in each code word;
  - 15 11) Burst error of 40 C1 code words with 5 errors in each code word;
  - 12) Burst error of 40 C1 code words with 5 errors in each code word.
- 20 Both, the inventive CIRC decoder and a conventional CIRC decoder can correct burst error of 14 completely corrupted C1 code words. It is apparent that, compared with a conventional CIRC decoder, advantageously the inventive CIRC decoder is able to correct burst errors of 20 C1 code words
- 25 having 3 or 4 errors in each code word.
- In case each code word having 5 and 6 errors, the decoder is not able to correct the burst error, but the flagged byte rate of the audio data is still significantly lower than with a conventional CIRC decoder.
- 30 Better correcting performance is also obtained with '30 C1 code word' burst error. The inventive CIRC decoder is able to correct burst errors of 30 C1 code words having three errors in each code word, and the flagged byte rate is also lower for higher error numbers per code word.
- 35
- It is to be noted that separate controlling and addressing

of four separate memories increases significantly the speed of the inventive CIRC decoder.

5 Parallel controlling and addressing of the M1, M2,a memories and the M2,a, M2,b memories during read and write operations also significantly increases the speed of the inventive CIRC decoder.

10 Memories with smaller sizes are used for de-interleaver implementations as compared with the above-mentioned CIRC decoder.

The de-interleaver task is performed in the M2,a memory during the first pass.

15

The size of the M2,a memory is  $110 \times 32 \times 9$ . The de-interleaver task is performed in the M2,b memory during the second pass. The size of the M2,b memory is  $1404 \times 9$  (conventional de-interleaver).

20

A memory with size  $256 \times 32 \times 9$  is used for both de-interleavers in the above-mentioned CIRC decoder.

25 The two-symbol delay task is performed in the M3 memory. The M3 memory operates as a look up table, which also increases the operational speed of the CIRC decoder.

In the inventive CIRC decoder it is possible to execute the single pass mode of the CIRC decoder.

30 The present decoding method is suitable to use the so-called erasure correction method of the RS code. Correction of large burst errors of C1 corrupted code words is very effective by low input error rate (each C1 code word comprises at most up to 6 random errors).

35





Claims

1. Method for cross interleave Reed-Solomon code correction comprising the steps of:
  - 5 - inputting a first C1 codeword into C1 decoder means from a first memory means;
  - outputting a second C1 codeword into a second memory means from the C1 decoder means;
  - de-interleaving the second C1 codeword to produce a  
10 first C2 codeword in the second memory means.
2. Method according to claim 1, wherein the second C1 codeword being the corrected first C1 codeword, in case the first C1 codeword is correctable and the second C1 codeword being a copy of the first C1 codeword in case the  
15 first C1 codeword is not correctable.
3. Method according to claim 2, wherein an erasure flag is set for each symbol in the second C1 codeword in case  
20 the first C1 codeword is not correctable.
4. Method according to one of claims 1 to 3, further comprising the steps of:
  - inputting the first C2 codeword into C2 decoder means  
25 from the second memory means;
  - outputting of a second C2 codeword into the second memory means from the C2 decoder means.
5. Method according to claim 4, wherein the second C2 codeword is the corrected first C2 codeword in case the  
30 first C2 codeword is correctable, and the second C2 codeword being a copy of the first C2 codeword in case the first C2 codeword is not correctable.
- 35 6. Method according to claim 5, further comprising setting an erasure flag for each symbol in the second C2 code-

word in case the first C2 codeword is not correctable.

7. Method according to one of claims 1 to 6, further comprising:
  - 5 - inputting the second C1 codeword into the C1 decoder means from the second memory means;
  - outputting a third C1 codeword into third memory means from the C1 decoder means;
  - de-interleaving the third C1 codeword to produce a third  
10 C2 codeword in the third memory means.
8. Method according to claim 7, wherein the third C1 codeword being the corrected second C1 codeword in case the second C1 codeword is correctable, and the third C1  
15 codeword being a copy of the second C1 codeword in case the second C1 codeword being not correctable.
9. Method according to claim 8, further comprising setting an erasure flag for each symbol in the third C1 codeword  
20 in case the second C1 codeword is not correctable.
10. Method according to one of claims 7, 8 or 9, further comprising:
  - inputting the third C2 codeword into the C2 decoder from  
25 the third memory means;
  - outputting a fourth C2 codeword into a fourth memory means from the C2 decoder means.
11. Method according to claim 10, wherein the fourth C2  
30 codeword being the corrected third C2 codeword in case the third C2 codeword is correctable, and the fourth C2 codeword being a copy of the third C2 codeword in case the third C2 codeword is not correctable.
- 35 12. Method according to claim 11, further comprising setting an erasure flag for each symbol in the fourth C2 code-

word in case the third C2 codeword is not correctable.

13. Computer program product comprising program means for  
performing a method in accordance with one of the claims  
5 1 to 12.

14. Reed-Solomon decoder comprising means for cross inter-  
leave Reed-Solomon code correction in accordance with a  
method of one of the claims 1 to 12.

10

15. Audio or video device, for example a CD or DVD player or  
recorder, comprising a Reed-Solomon decoder in accor-  
dance with claim 14.



Abstract

The invention relates to a method for cross interleave Reed-Solomon code correction comprising the steps of:

- 5           - inputting of a first C1 codeword into C1 decoder means from a first memory means,
- outputting of a second C1 codeword into a second memory means from the C1 decoder means,
- de-interleaving the second C1 codeword to produce a
- 10           first C2 codeword in the second memory means.

(Figure 2)



Drawing:-

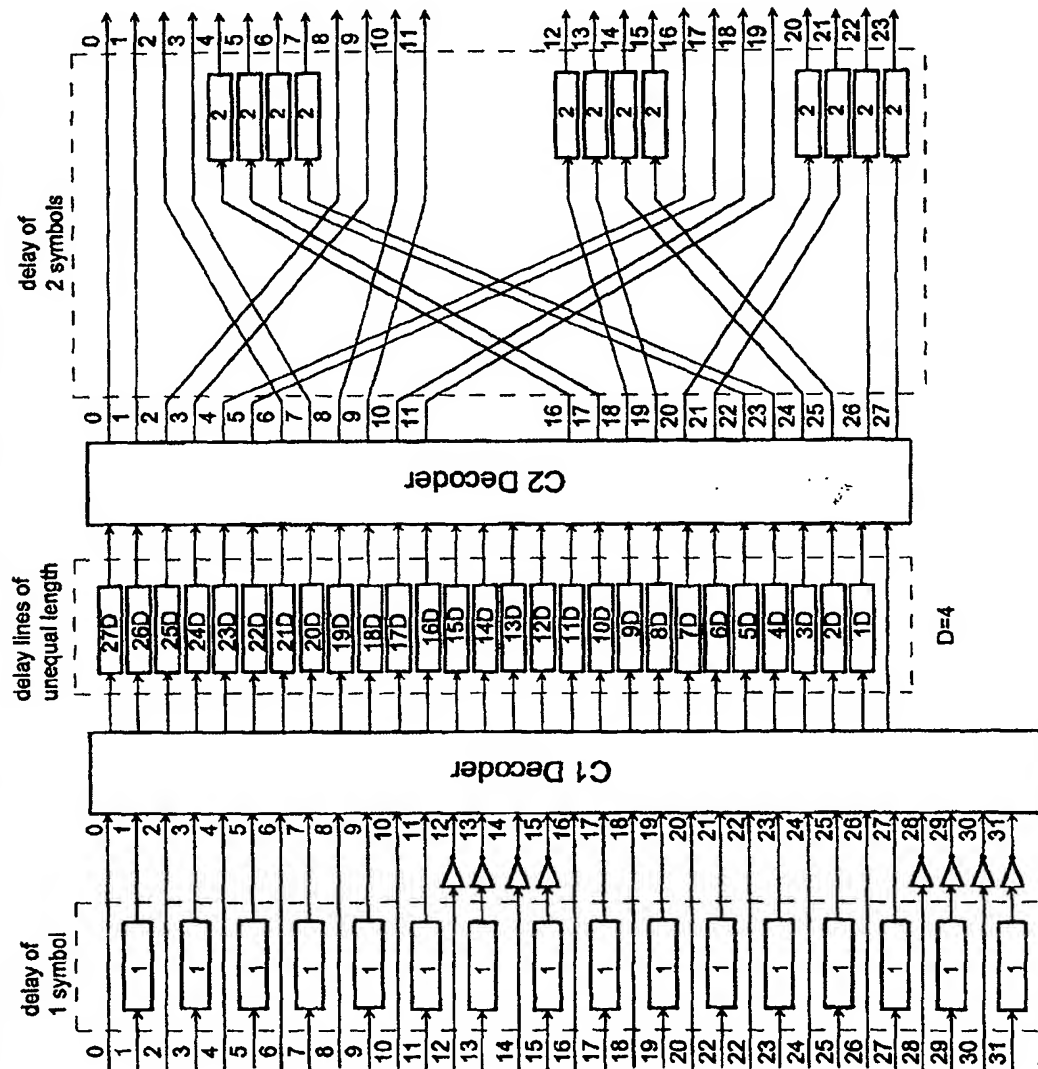


Fig. 1

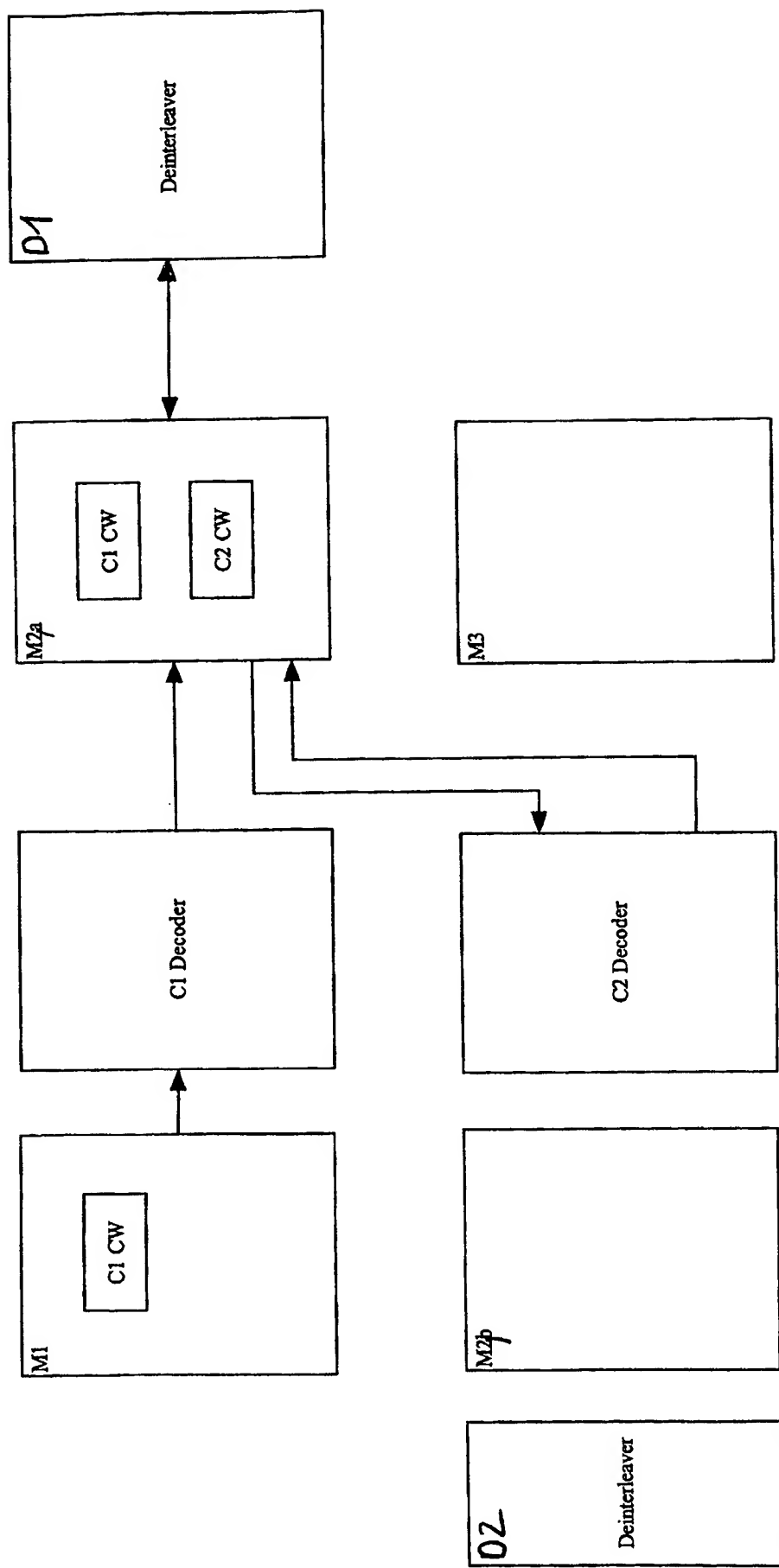


Fig. 12



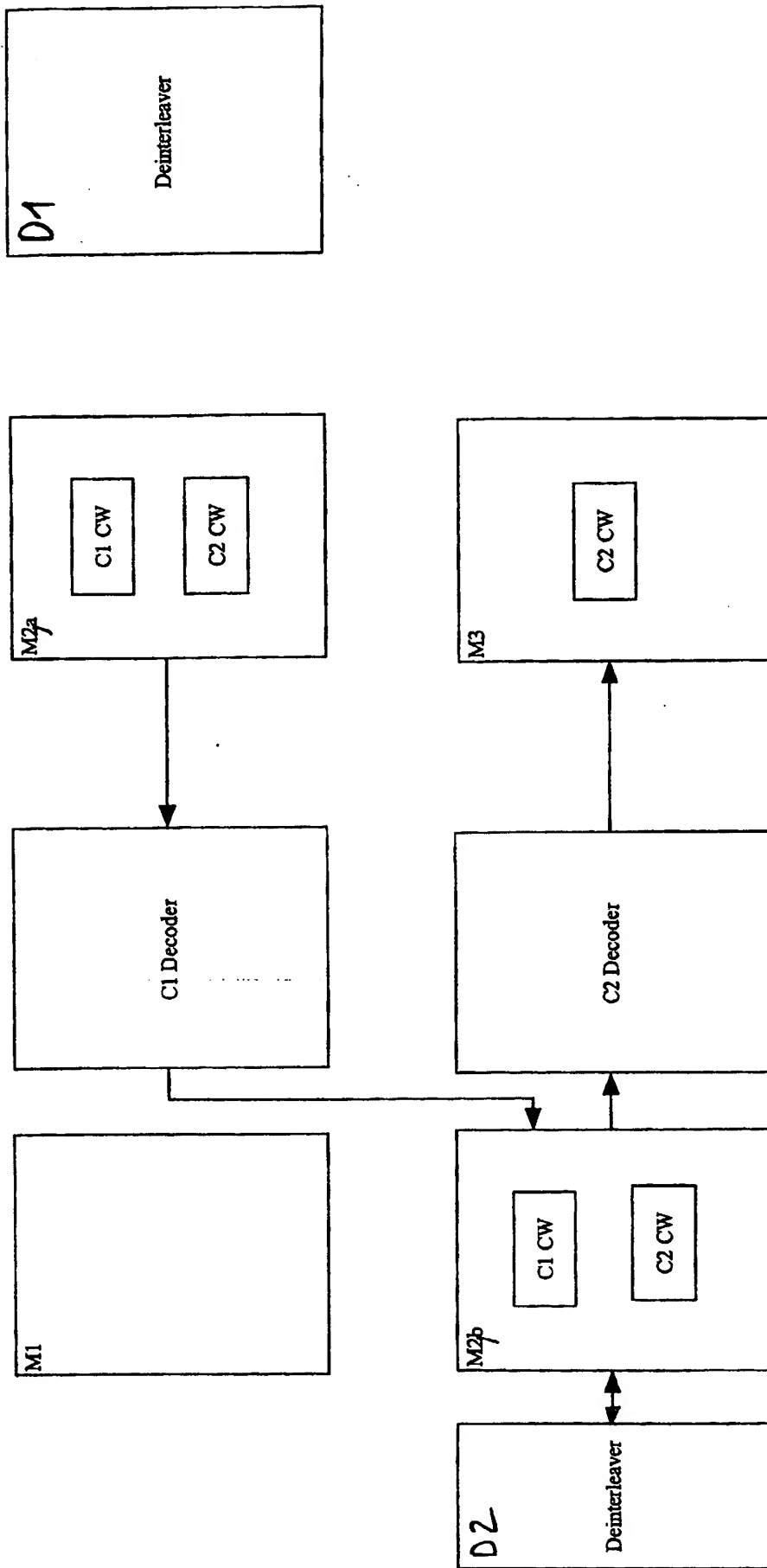


Fig. 3

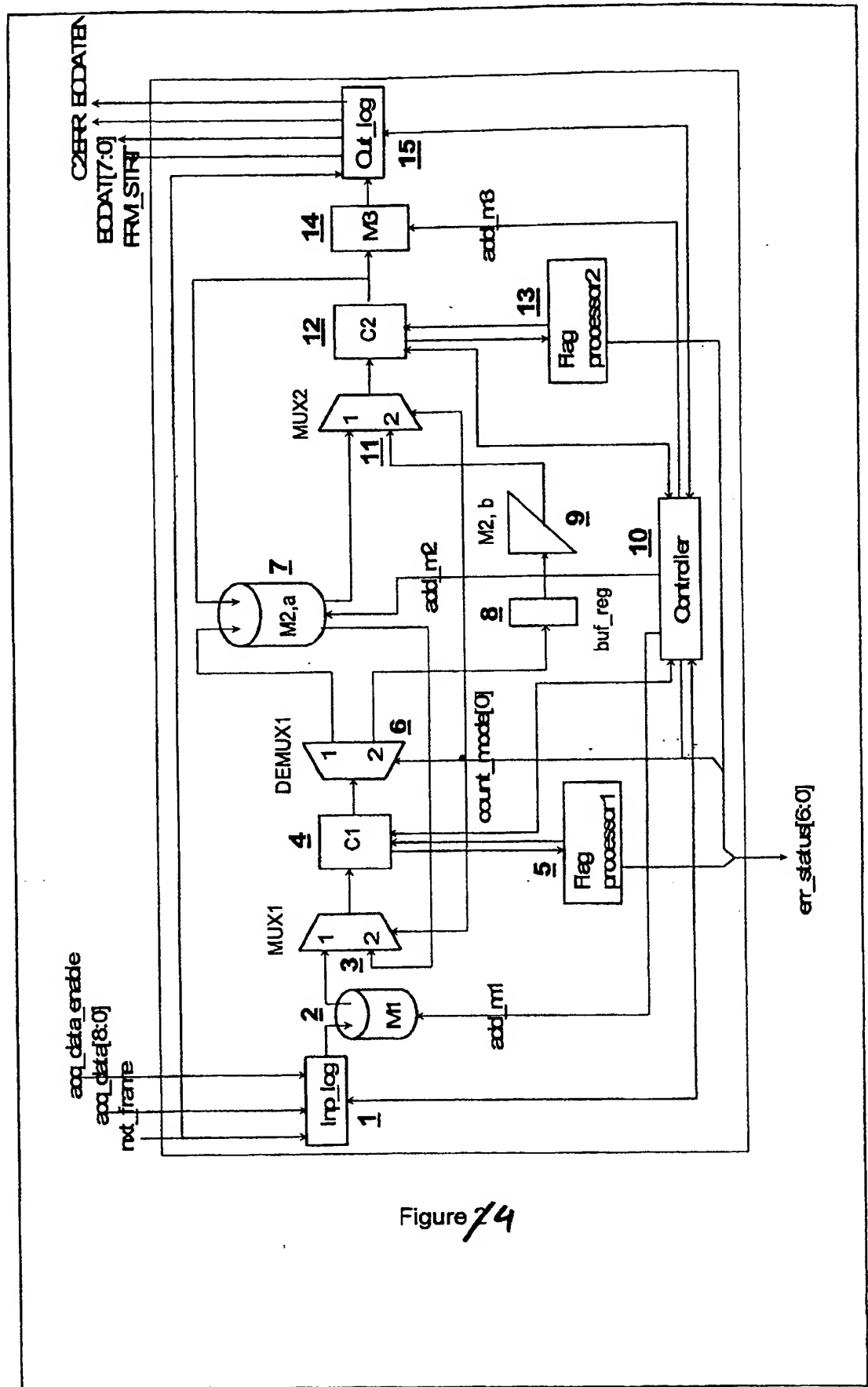


Figure 74

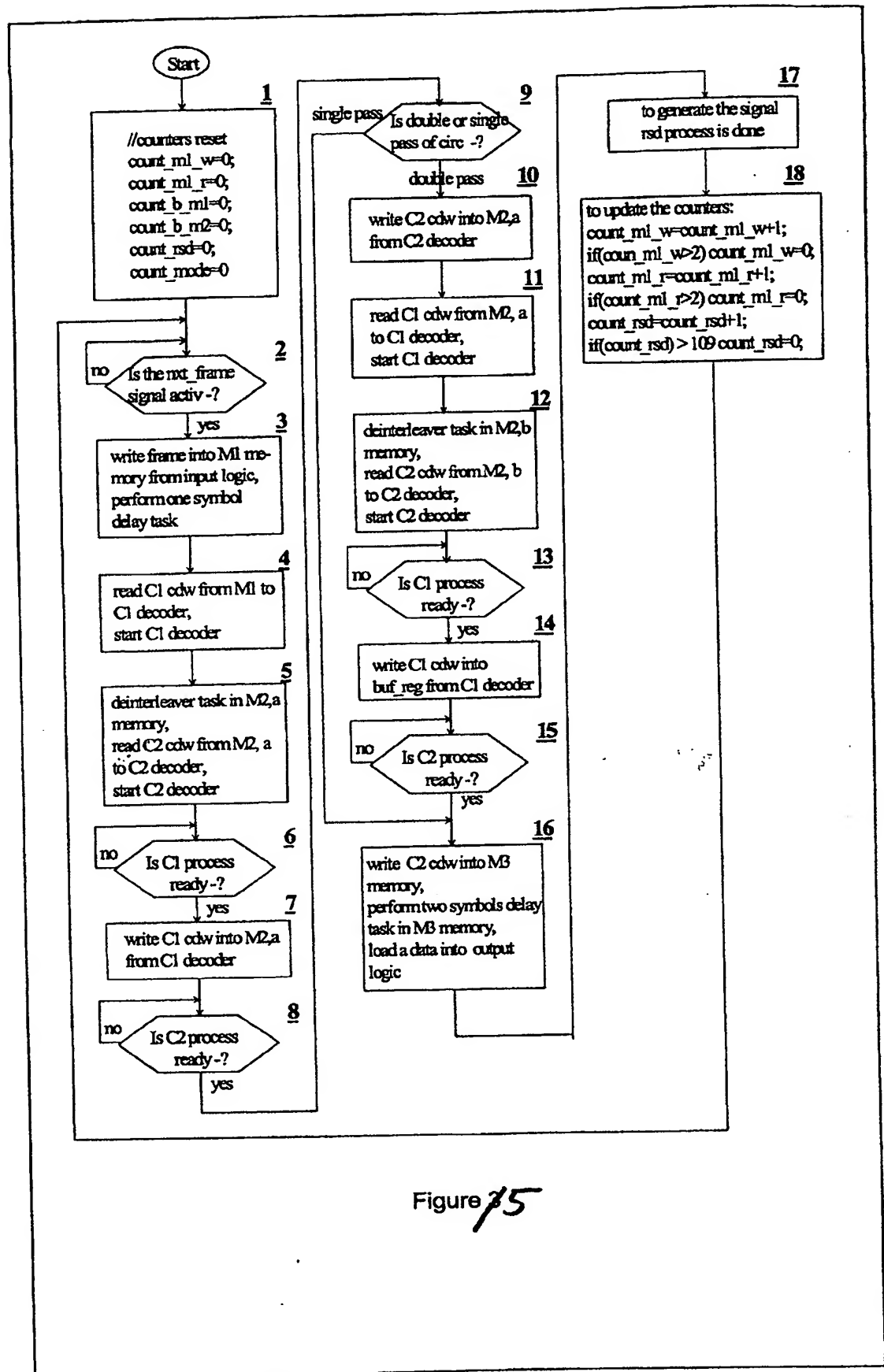
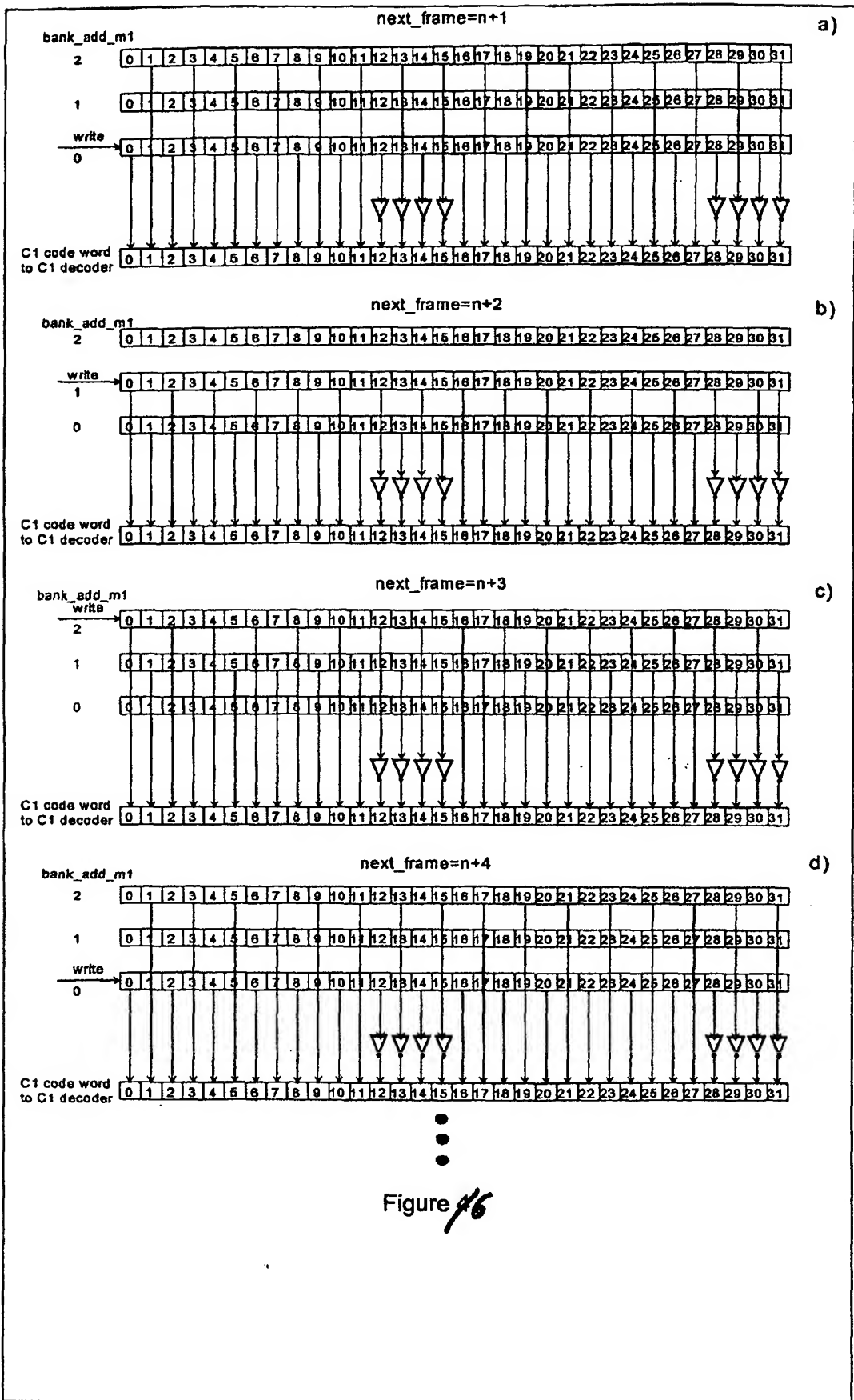
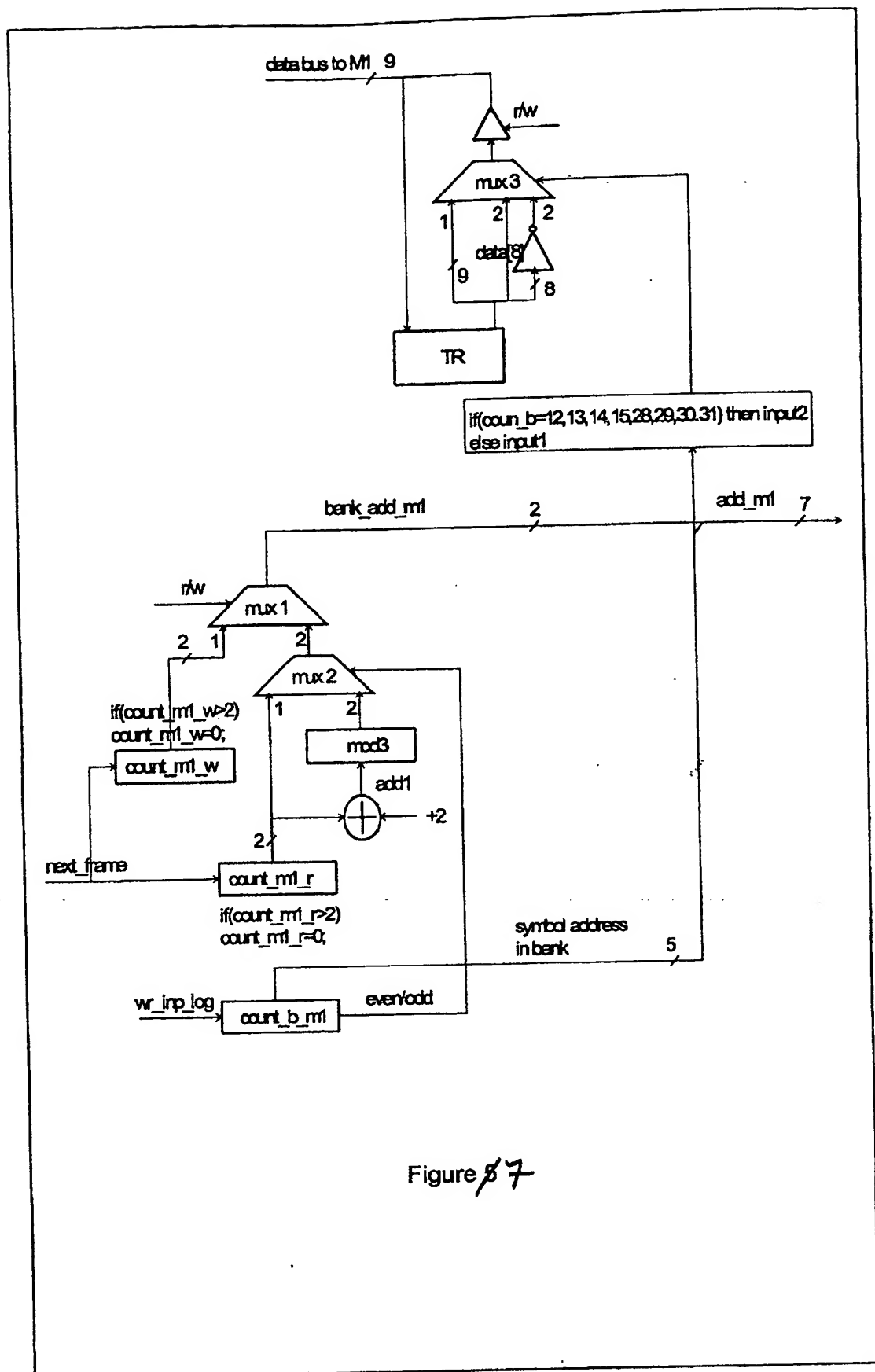


Figure 75





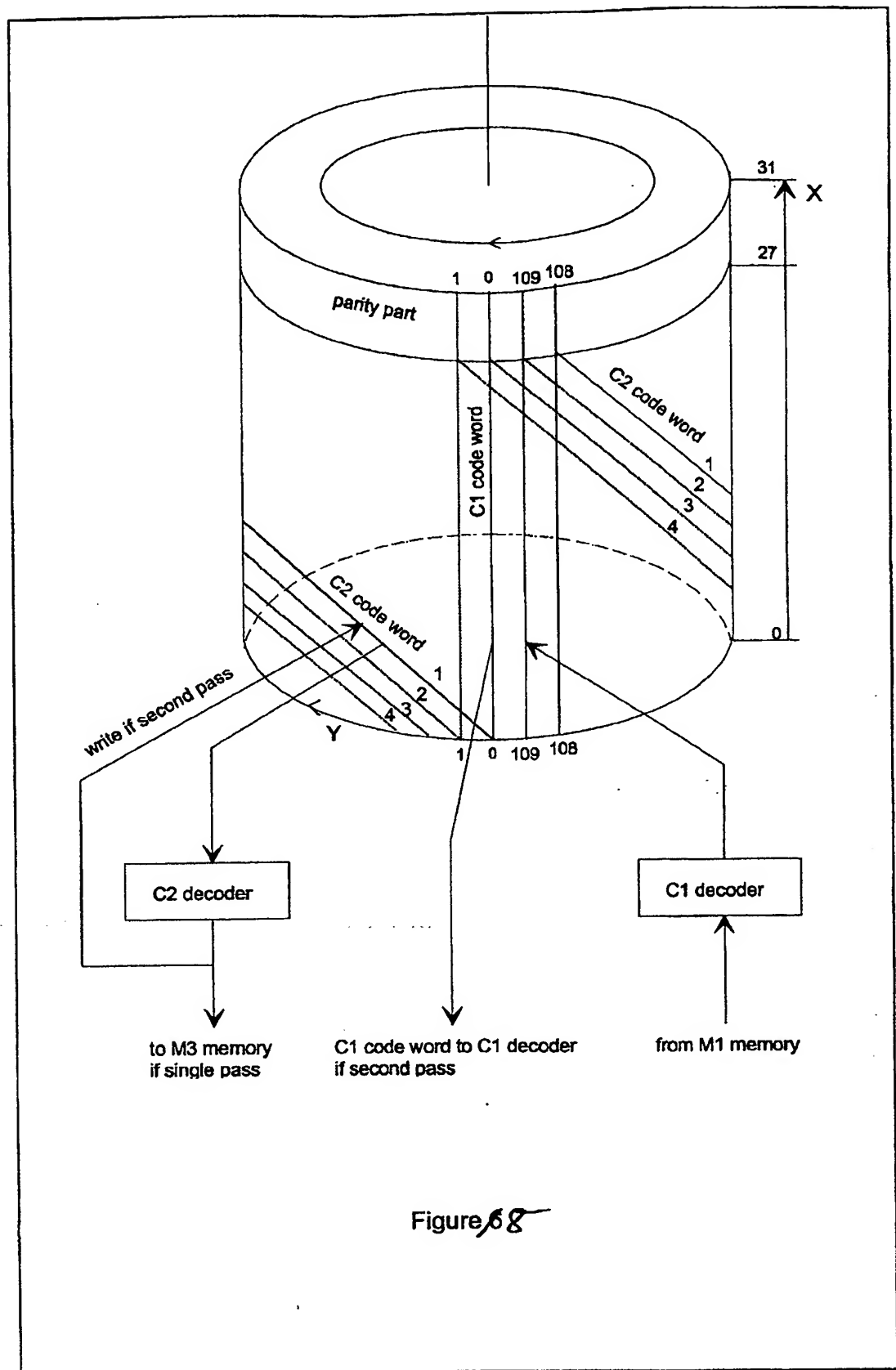


Figure 68

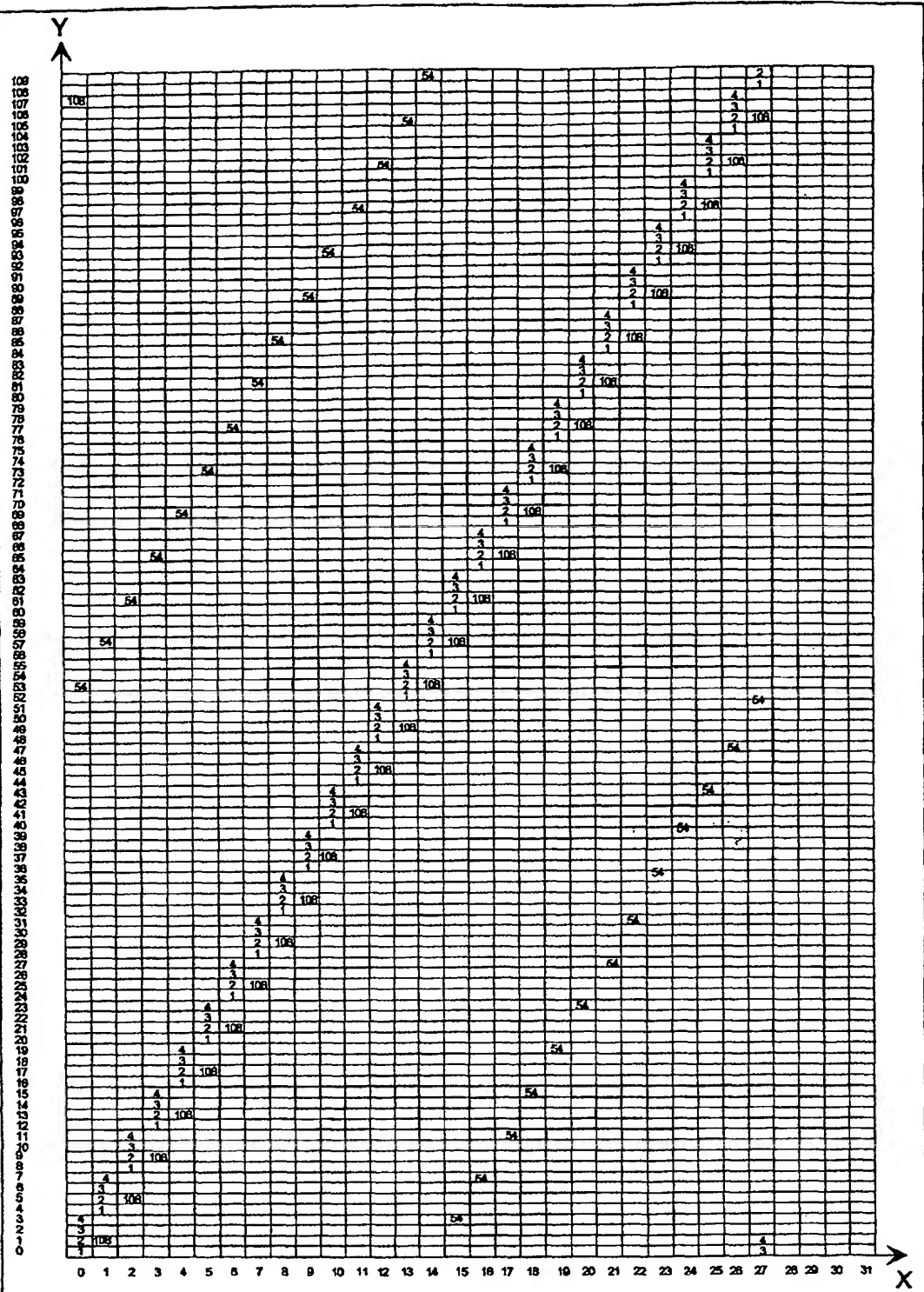
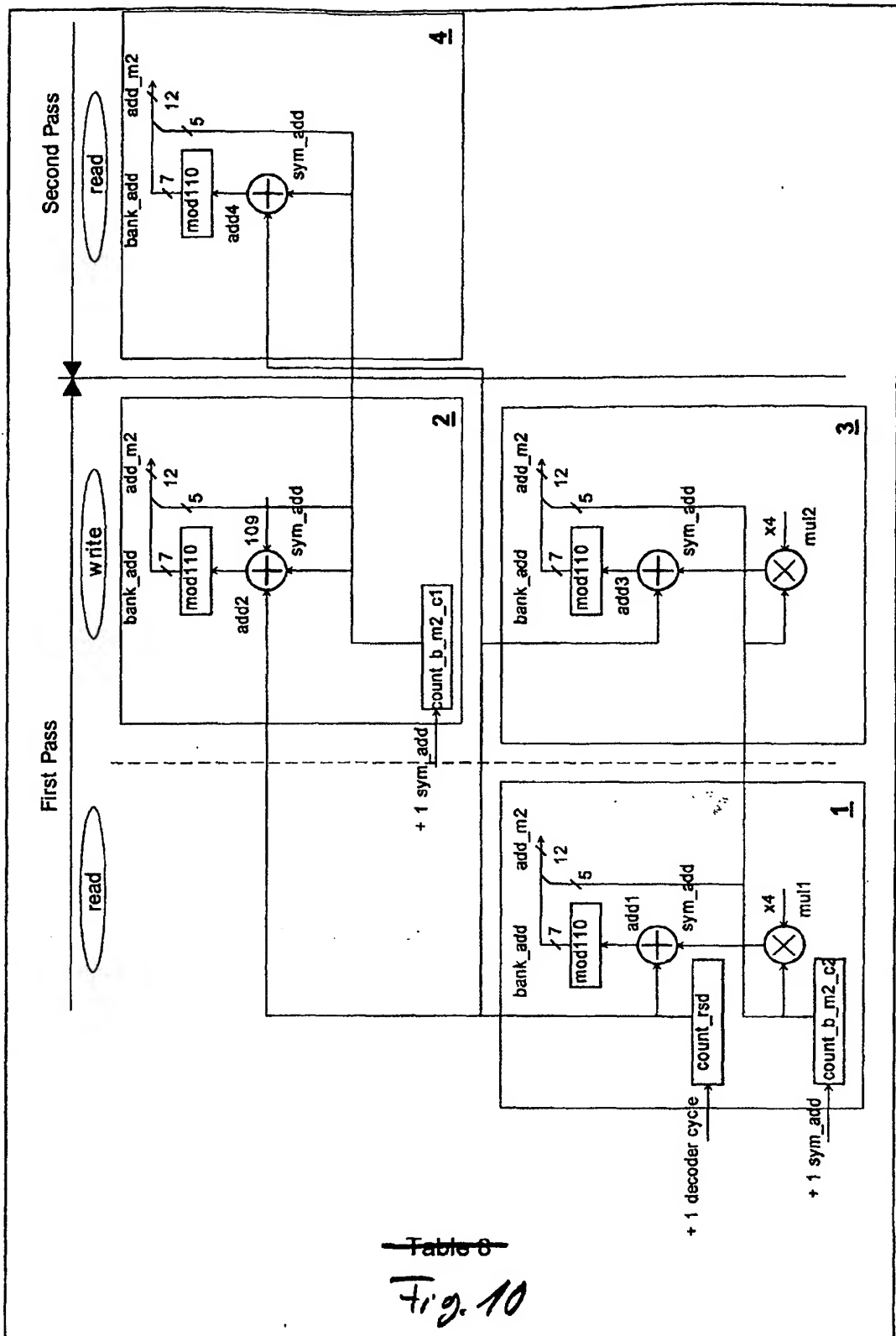


Figure 79





flagged bytes  
rate of audio data

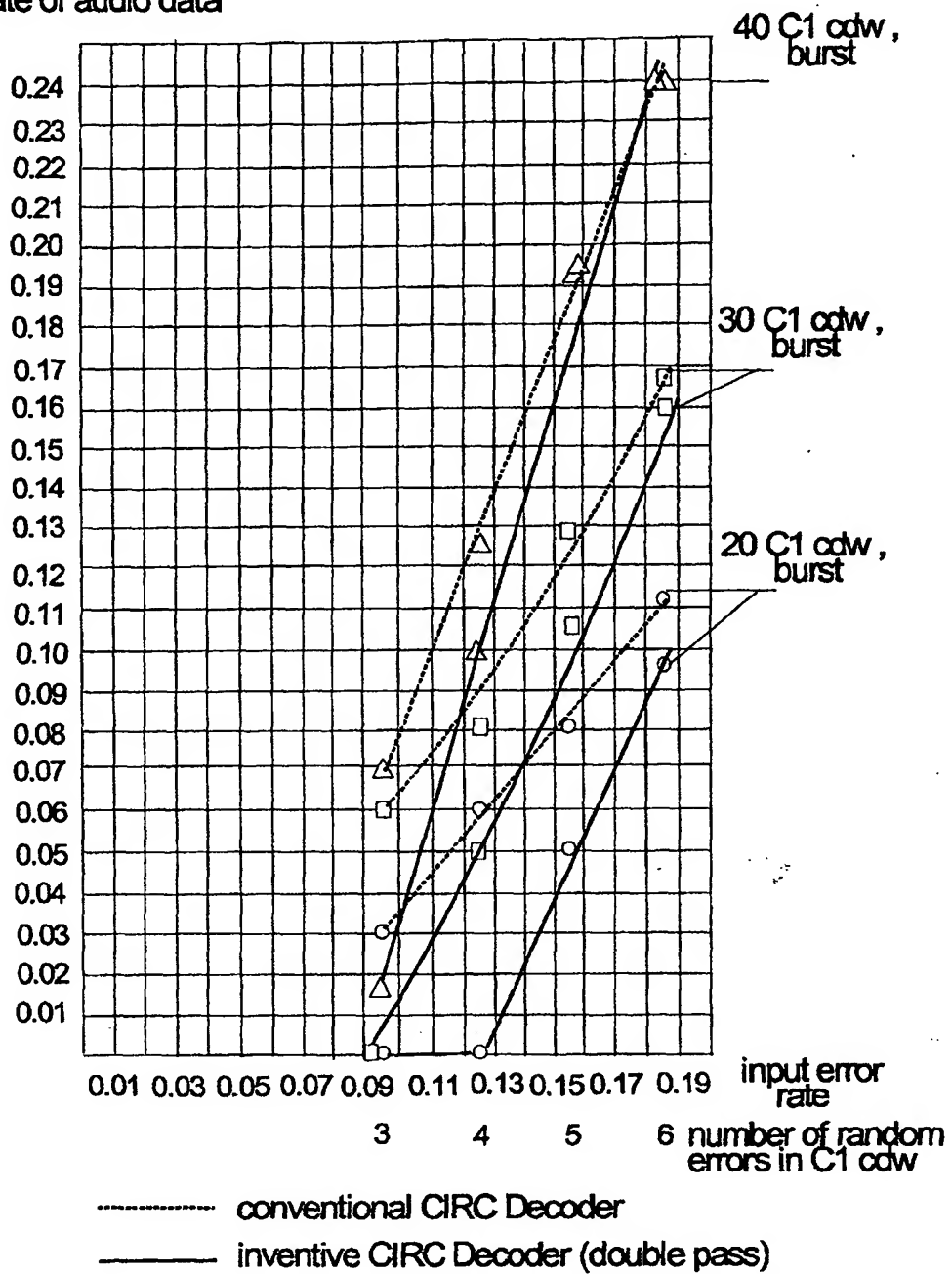


Table 9

Fig. 11

